FEASIBILITY OF HYDROGEN ENERGY PRODUCTION THROUGH NATURAL GAS STEAM REFORMATION PROCESS IN THE UAE

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Abstract

This paper presents a feasibility study of producing environmental friendly hydrogen energy through natural gas steam-reformation process in the UAE, which has estimated natural gas reserves of 224.9 X 10^9 GJ. The current findings demonstrated that the cost of hydrogen energy produced by steam-reformation is approximately \$8.2/GJ, which is 10%, 45% and 57% less than hydrogen produced through biomass gasification, solar-hydrogen and wind-hydrogen, respectively. Moreover, The total amount and cost of carbon emitted by natural gas steam-reformation are calculated to be 48 Kg-CO_2/GJ and \$6.7/GJ, respectively. These values were considered to be more favorable in comparison with other fossil fuels and hydrogen producing methods.

Keywords: Hydrogen energy, PEM fuel cell, natural gas steam-reformation, carbon emission

1. Introduction

United Arab Emirates (UAE), which is considered to be one of the leading countries in the world in natural gas production, currently produces approximately 3 billion cubic feet per day (bcf/d), and it is expected to reach 4 bcf/d by the year 2005. Energy Information Administration EIA, estimated that UAE's reserves of the natural gas are about 224.9 X 10^9 GJ, which is considered world's fourth-largest natural gas reserves after Russia, Iran and Qatar. Over 90% of UAE's reserves of natural gas are in the emirate of Abu Dhabi, which has been supplying Japan most of its liquefied natural gas (LNG) since 1977 [1]. In order to fulfill the rapid demand of natural gas in the energy market, UAE has embarked major NG-intensive projects, specially the multi-billion \$US Dollars Dolphin project, which interconnects pipelines between Qatar, UAE and Oman and with possible links to Indian subcontinent [2].

In recent years, the environmental concerns of the developed countries and their determination of implementing the Kyoto-commitment has led them to seek a suitable environmentally-friendly energy alternative that could be relied on for future energy needs. Many scientists, energy economists, and energy policy makers believe that hydrogen energy, which possesses significant characteristics such as being

T.N. Veziroglu et al. (eds.),
Hydrogen Materials Science and Chemistry of Carbon Nanomaterials, 467-472.

environmentally clean, storable, transportable and inexhaustible, could play a key role in fulfilling the global energy demand without any environmental sacrifices. Presently, utilization of hydrogen energy to run fuel cells for a clean power generation has gained worldwide attention. Fuel cells especially proton exchange membrane fuel cells (PEMFC) have been playing a significant role in industrial, utilities and transportation sectors of many developed countries such as Japan, USA and Germany. Thus, UAE could play a key role in supplying the developed countries with hydrogen energy produced from natural gas reformation in order to fulfill their Kyoto commitment.

The objective of the current study is to conduct a feasibility study of hydrogen energy production by natural gas steam-reformation process in the UAE. The analysis is to be performed at various scenarios (%) of natural gas used in hydrogen production. Moreover, the total cost of hydrogen produced by 10% of NG as well as the total amount and cost of carbon emitted by natural gas steam-reformation are to be compared against other fossil fuels and hydrogen producing methods.

2. Technical, economical and environmental considerations

Production of hydrogen can be achieved through either utilizing conventional resources such as oil and natural gas steam-reformation, coal gasification or by renewable resources such as biomass gasification, solar-hydrogen and wind-hydrogen and hydropower electrolysis processes. Globally, around 400 billion cubic meters of hydrogen are produced annually with natural gas steam-reformation process, is considered to be the most common and cost effective hydrogen producing method [3]. Approximately, 48% of worldwide hydrogen energy is produced from this process; even experts have recommended mass production of small-scale natural gas reformers, supplying direct hydrogen for stationary fuel cells and at vehicle refueling stations.

Natural gas steam-reformation is a two-step process in which four parts hydrogen are produced from one part methane and two parts water at high operating temperatures and pressures and in the presence of a catalyst. This process is relatively efficient and inexpensive and it can be made still more efficient through cogeneration, which utilizes waste heat. Hence, making steam-methane particularly attractive for local use.

Hydrogen production is based on large-scale plants operating at an average capacity factor of 90%, capable of producing 36,000 GJ of H_2 per day, which is sufficient to fuel 500,000 proton exchange fuel cell vehicles (PEMFCV). On the other hand, small-scale plants would be capable of producing 180 GJ of H_2 per day, which is sufficient to fuel approximately 2,200 PEMFCV's [9]. However, hydrogen production through large-scale plants is more favorable for high-hydrogen demanding applications such as transportations and electric power generation.

Practically, there are two major drawbacks associated with natural gas steam-reformation process. Firstly, steam-reformation method is not the best method for hydrogen production due to low level of operating efficiency. Secondly, the emission associated with this type of process emits substantial amount of carbon dioxide, which could have a major impact on the environment.

The efficiency of the steam-reforming process, which is defined as the ratio of the heating value of the produced hydrogen over the energy input of the raw material in terms of fuel and electricity, is about 65-75% [4]. On the other hand, efficiency of renewable electrolysis technology, which refers to the process of splitting water powered

by an electric current to produce hydrogen, is about 80-85%. Since hydrogen production through steam reformation of natural gas is highly exothermic process, the plant generates more steam than it consumes. Thus, energy efficiency of the steam-reformation plant could be drastically increased by at least 10% if the excess steam generated by the plant is used for another source [5], and it could compete with renewable electrolysis technology.

Experimentally, natural gas is considered to be the least polluting fossil fuel as opposed to oil and coal. It contains mixture of various components such as methane (CH_4), ethane (C_2H_6), propane (C_3H_8) and other types of hydrocarbons, carbon dioxide (CO_2), etc., which results difficulty in predicting the performance of the steam reformation plant [6]. Of all the above-mentioned components, CO_2 could be the major emitted component that should be dealt with extreme caution due to its greenhouse effect. By using technologies to capture CO_2 for either safe, long-term storage or use as a commercial commodity or carbon sequestration technologies, that will lower carbon emission to the minimum. Thus, hydrogen production through renewable resources would be more environmentally attractive as compared with natural gas reformation. Research from the US National Renewable Energy Laboratory has found that hydrogen produced from wind electrolysis results in greenhouse gas emissions that are one-twelfth those of a large natural gas reformer [7].

Generally, cost of hydrogen produced from steam-reformation process, fluctuates with the fluctuating price of natural gas. However, it is proved to be more favorable in the near-term than hydrogen produced from renewable methods (approximately $0.65/kg if it is consumed at site and $1-$2/kg for hydrogen produced by electrolysis) [8]. On the other hand, cost of hydrogen produced from natural gas is predicted to increase by 70% in the long-term due to increase in the cost of natural gas as a result of its massive utilizations and its imminent scarcity in the near future [9].

In order to reduce the carbon emission to 1990 level set by the Kyoto protocol, a suggested carbon emission tax of $140/tonne-$CO_2$ was set in accordance with the current study presented by L. Horwitz [10]. He concluded that a $100 per tonne of CO_2 would not be sufficient to bring emissions back to 1990 levels and a tax of $200 per tonne of CO_2 would be more than enough to eliminate growth in emissions. Department of Energy, suggested a carbon tax of $14, which seems to be unrealistic and it will not be sufficient to meet the level set in Kyoto-protocol.

3. Results and discussion

The current analysis was performed based on the UAE's current production of natural gas, which is about $1.1X10^9$ GJ/year as opposed to the average production in the next 100 years period of $2.11X10^9$ GJ/year to fulfill the demand in the energy market [11]. Depending on the pace at which the government is welling to shift toward a cleaner production of energy, the analysis was conducted at various scenarios (%) of natural gas to be used in hydrogen production through steam reforming process. In Figure 1, a cost breakdown was conducted on hydrogen production at NG utilization rate of 10%, 50% and 100% of the country's present NG production. Clearly, the higher the utilization rate of natural gas (%), the more cost effective hydrogen is produced and stored. For instance, at 100% utilization of NG, the capital cost of NG steam reforming plant would be approximately $1.4/GJ, which is 50% less than 10% of utilized NG. Similarly, the

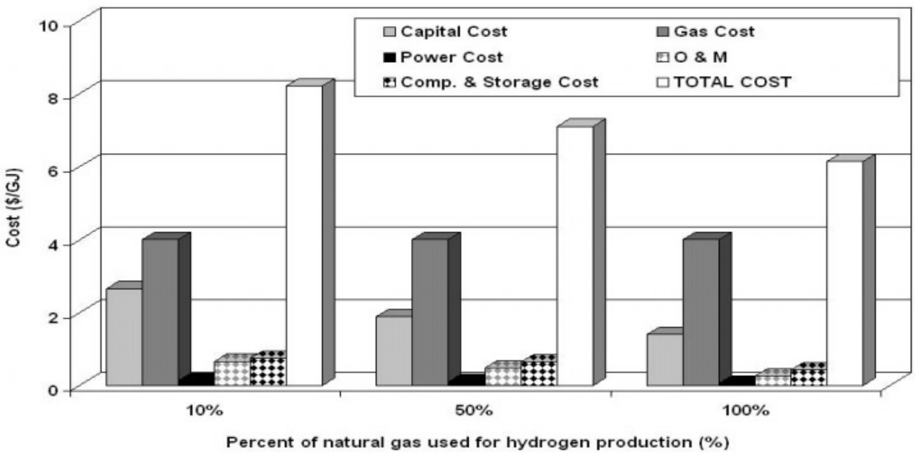

Figure 1: Cost breakdown of hydrogen production at various percentages of current production of natural gas.

operation and maintenance cost (O&M) and compression and storage cost of hydrogen at 100% NG utilization would be $0.265/GJ and $0.45/GJ, respectively. These values are estimated to be 60% and 45% less than hydrogen produced at 10% NG utilization. In general, the total cost of hydrogen produced at 100% NG utilization would be approximately $6.15/GJ, which is 25% less than at 10% NG utilization if an average cost of natural gas is set to be $4/GJ [11].

Cost of hydrogen produced by 10% of NG steam reforming is considered to be more attractive than hydrogen produced by biomass gasification or by solar-hydrogen or wind-hydrogen methods as depicted in Figure 2. However, the capital cost of NG steam-reforming plant is $1.225/GJ more than biomass gasification plant, which is $1.45/GJ. Nevertheless, the capital cost of NG steam-reforming plant is 3 times less than the capital cost of solar-hydrogen or wind-hydrogen plants. Furthermore, utilization of renewable resources (solar and wind) requires electrolysers, which could add more to the total cost of hydrogen. An average cost of solar-PV assisted electrolyser would be about $3.9/GJ of hydrogen produced. And, the average cost of wind-power assisted electrolyser would be about $5.5/GJ of hydrogen produced. The total cost of hydrogen produced by 10% of NG is $8.2/GJ, which is 10% less than hydrogen produced through biomass gasification. Moreover, the total cost of hydrogen produced by 10% of NG is 45% and 57% less than solar-hydrogen and wind-hydrogen energy systems, respectively.

The total cost of solar-hydrogen and wind-hydrogen are considered to be far more than other hydrogen energy producing methods, although they do not contribute any environmental damages such as carbon emission as depicted in Figure 3. The total amount and cost of carbon emitted by natural gas steam-reformation are respectively estimated to be 48 kg-CO_2/GJ and $6.7/GJ, which are regarded to be the least among other fossil fuels and hydrogen production methods. Conversely, the total amount and cost of carbon emitted by coal gasification to produce synthetic fuels are considered to be the highest among other sources and methods, and they are estimated to be 145 kg-CO_2/GJ and $20/GJ, respectively. The emission cost presented in the study is based on $140/tonne-$CO_2$, which could be set to reach the limit assigned in Kyoto. This value is more reasonable than the value suggested by the EPA of $14/tonne-$CO_2$ [10].

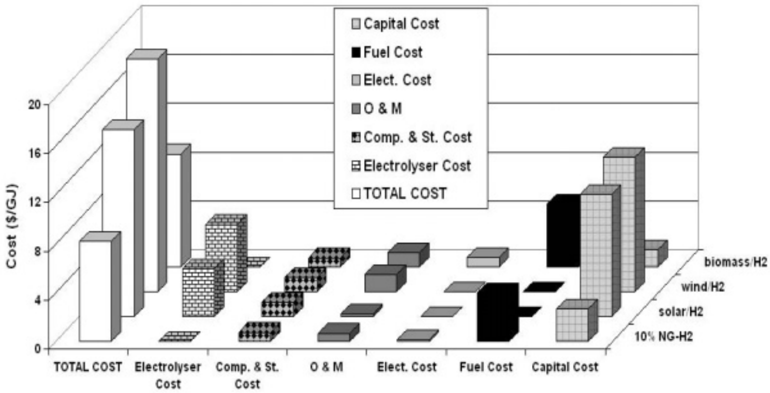

Figure 2: Cost comparison between hydrogen production by 10 % NG at current production and other types of hydrogen producing methods.

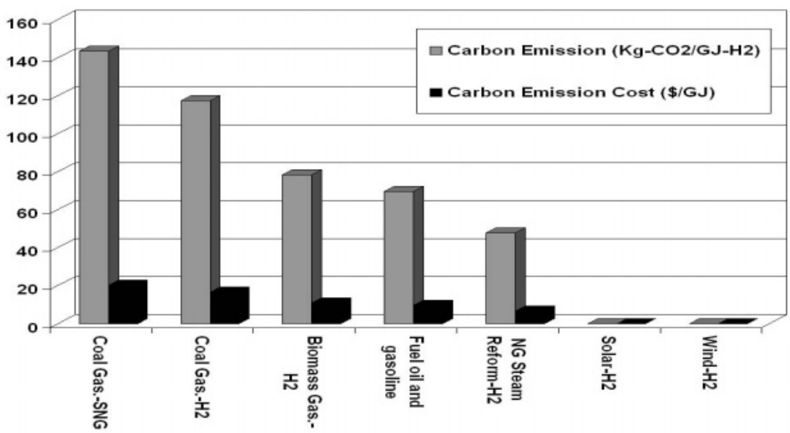

Figure 3: Amount and cost of carbon emission from various types of energy producing methods.

At a worst-case scenario, hydrogen could be produced at a 10% of current NG production, which is plausible for the UAE and increase the quota gradually as the demand increases. In addition, hydrogen could be added to the natural gas and exported overseas as a mixture, which could have some advantages when compared with natural gas alone. For instance, a mixture of hydrogen and natural gas can be used in internal combustion engines and fuel burners, emitting less pollutant, such as CO_2, SO_x, NO_x, HCs and CO to the atmosphere [12, 13]. Also, the amount of hydrogen in the H_2/NG mixture could be increased in hydrogen content with the increase in the percentage of NG used in the reformation process.

4. Conclusions

Feasibility study on hydrogen energy production in the United Arab Emirates through natural gas steam reformation process was carried out. The analysis was performed at various scenarios (%) of natural gas used in hydrogen production through steam

reforming process. In addition, the analysis was conducted to compare the total cost of hydrogen produced by 10% of NG as well as the total amount and cost of carbon emitted by natural gas steam-reformation against other fossil fuels and hydrogen producing methods.

With the country's substantial potential of natural gas reserves, hydrogen could be produced at an economical rate of at least \$6.15/GJ based on 100% of current NG utilization. This rate is 25% less than hydrogen produced at a more conservative rate of 10% NG taking into consideration the average cost of natural gas of \$4/GJ. Nevertheless, the cost of hydrogen produced at a 10% of NG is more attractive than any other hydrogen producing methods. Furthermore, the total amount and cost of carbon emitted by natural gas steam-reformation are estimated to be 48 kg-CO_2/GJ and \$6.7/GJ, respectively. These values were considered to be more favorable in comparison with other fossil fuels and hydrogen producing methods. Finally, it should be pointed out that hydrogen could be added to natural gas to form a H_2/NG mixture and exported overseas taking into consideration, a gradual increase of hydrogen content in the mixture in the event of increase in the percentage of NG used in the steam-reformation process.

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